OXYGEN PLASMA STRIPPING OF PHOTORESIST FROM BIPOLAR INTEGRATED CIRCUIT WAFERS - PROCESS DEVELOPMENT

A THESIS

SUBMITTED TO THE FACULTY OF ATLANTA UNIVERSITY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

THE DEGREE OF MASTER OF SCIENCE

BY

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DEPARTMENT OF CHEMISTRY

ATLANTA, GEORIGA

JULY 1981

ABSTRACT

CHEMISTRY

ULANMO, PETER O. B.S. CLAFLIN COLLEGE, 1979

OXYGEN PLASMA STRIPPING OF PHOTORESIST FROM BIPOLAR INTEGRATED CIRCUIT WAFERS - PROCESS DEVELOPMENT

Advisor: Professors Malcolm B. Polk and Kofi B. Bota

Thesis dated July 1981

The development of a plasma strip process, in which an oxygen plasma removes photoresist films from etched silicon wafers, is described. The ultimate objective was to demonstrate that dry plasma stripping is a reliable, cost-effective, production-compatible process that does not compromise product reliability.

Optimum process parameters were determined to be an RF power level of 450 watts and an oxygen flow rate of 600 cc per minute. Metallized and glass-coated bipolar devices produced with the plasma stripping process have satisfactorily demonstrated production yield equivalency.

The end point of plasma stripping was determined quantitatively.

ACKNOWLEDGEMENTS

I would like to thank Delco Electronics Division of General Motors for supporting this project under the Student Intern Program. I will always be indebted to my supervisor, Robert Cashin, and engineers Janet Dieterly, Douglas Hamilton, Rita Rozenbaum, and David Swinehart for their guidance and encouragement throughout this study. My thanks to Victor Bristol and William Friz for their assistance in obtaining the Auger Electron Spectroscopy Spectra and Scanning Electron Microscope photographs, respectively.

I am grateful to Dallas Scherer for his assistance in photoresist applications, and to Dwight Callaway, General Superintendent, Manufacturing Development, and Robert Brockman, Manager, for the opportunity and exposure to the Semiconductor Industry. I dare not fail to mention the Failure Analysis Engineers for their cooperation in obtaining test results.

I am particularly grateful to Dr. Malcolm Polk and Dr. Kofi B. Bota for their many suggestions and assistance throughout my stay at Atlanta University. Many thanks to Dr. Frank Cummings and the Department of Chemistry for financial support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The replacement of wet processing with dry processing techniques is a recent development in the manufacture of integrated circuits.[1] Removal of photoresist films with the reactive oxygen plasma (first introduced in 1968)[2] is of particular interest; its adoption will eliminate the wasteful and time-consuming wet chemical techniques which have historically been associated with the industry.[3]

A plasma is an ionized gas which contains highly reactive particles such as ions, free electrons and free radicals.[4] This extreme reactivity has made it suitable for a wide variety of commercial applications. It is used in chemical milling, nitriding of steel, synthesis of organic polymers, and modification of polymer surfaces.[4,5] Its most important applications occur in microelectronics manufacturing, where it is used for etching semiconductor wafers, cleaning sensitive workpieces, and stripping photoresist from wafers and masks.[4,5]

Successful integrated circuit manufacturing depends on high-precision photolithographic techniques for pattern generation. The surface of the substrate to be patterned, normally a metal or insulator film, is coated with a layer of photosensitive polymer, called photoresist. The photoresist is then exposed to ultraviolet light through a mask having a desired pattern and the exposure causes the selective polymerization of the resist,[6] reproducing the pattern from the mask onto the wafer. This exposure imparts greater or less chemical resistance to the exposed

areas (depending on the type of photoresist used) when compared with the unexposed areas.[7]

There are two types of photoresist: positive and negative. A positive photoresist leaves a positive image, with respect to the mask used, in the irradiated resist film after the exposure and development process[8] (the photoresist remains where it is not exposed to light). A negative photoresist leaves a negative image of the mask used on the coated substrate[8] (the photoresist remains where it is exposed to ultraviolet light).

The present discussion deals primarily with a type of negative photoresist known as Hunt Resist 43, Type 31C. Table 1 shows the properties of this material. Negative photoresists have high chemical resistance, good image reproduction qualities and are generally of low cost.[7] They are generally more difficult to remove by traditional methods because of their high chemical resistance.[7] Until recently, photoresists have been removed by wet processing techniques, but the development of a dry process[2] promises to replace them soon.

The use of photoresists in the microelectronic industry requires an understanding of their behavior, and there are unique features of this behavior as it relates to the dry process. Detailed information regarding photoresists, initiators, or sensitizers is limited, as they are proprietary materials. In plasma stripping, chemical resistance is not a factor; rather, the interaction of the plasma with the resins in the photoresist is most important.

Table 1. Properties of Hunt Resist 43, type 3IC.*

Specific Gravity	0.900
Surface Tension (Dynes/cm)	28.3
N^{D}_{20} (Index of Refraction)	1.5035 (solution)
	1.5465 (dry film)
Viscosity (Centipoise)	41 3
Solids (Wt. Percent)	13.2 0.3
Flash Point Temperature (°C)	29
Threshold Limit Value (ppm by volume)	100

Inorganic Residuals:

Boron	1.0 ppm
Aluminum	1.0 ppm
Chromium	1.0 ppm
Iron	1.0 ppm
Manganese	1.0 ppm
Sodium	1.0 ppm
Nickel	1.0 ppm
Tin	1.0 ppm

*Taken from Hunt Chemical Corporation, Technical Bulletin No. 41 (Not Dated).

The site of interaction with the plasma seems to be the unsaturation (double bonds) in the resin, and depends on its nature and location in the molecular structure.[9] Polyisoprene derivatives have been the most widely used photoresist resins in microelectronic photoresist application[7] and there are many different structural configurations as can be seen in Figs. 1a, b, c. Knowing that polyisoprene is the resin in photoresist has been helpful. However, this is not enough to understand the nature of photoresist because some or all of the different configurations of polyisoprene can occur in the same photoresist polymer.[9] The difference in Figs. 1a, b, and c, is the location of unsaturation. It has been observed that the structure with the double bond located on the polymeric chain backbone (Fig. 1a) requires a longer plasma stripping time.[9] There is also the possiblity of cyclization (Fig. 2) by the structures in Figs. 1b and c, to form stable hexagonal rings with elimination of double bonds.[9] This structure is even more difficult to strip.[9]

The organic resin is not necessarily photosensitive, but it does have to be capable of becoming insoluble by undergoing a reaction with the sensitive molecule; e.g., ammonium dichromate, which has been activated by absorbed light energy.[7] Table 2 shows some other basic properties of negative photoresist resins. In the case of negative phototresists, which usually contain a linear polymer dissolved in a suitable solvent and a substance that absorbs light energy and brings about an insolubilizing reaction (a photosensitizer or initiator),[7,10] the exposed material is rendered insoluble in a developer (Fig. 3).

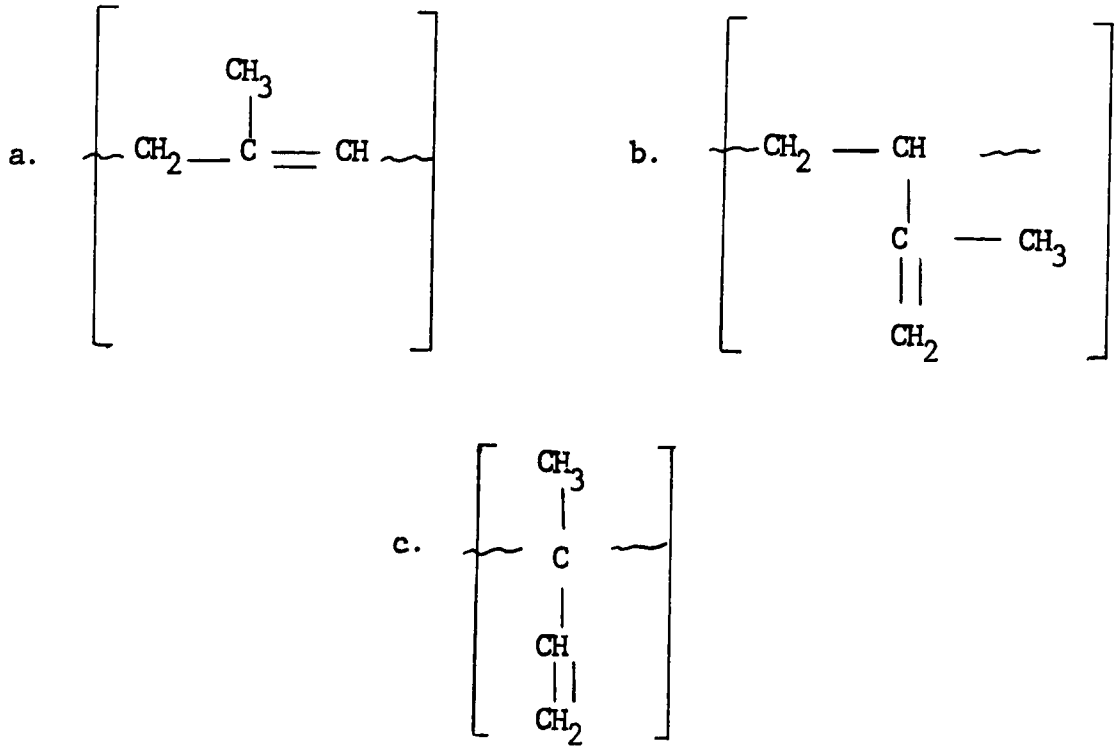


Fig. 1. Different structural configurations of polyisoprene.

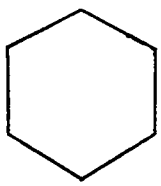


Fig. 2. Hexagonal ring.

Table 2. Basic Properties of Negative Resist Resins.*

The resin must be capable of being insolubilized upon exposure to actinic light.
Prior to exposure, the resin should be soluble in a solvent system.
The resin should be capable of wetting and adhering to a variety of surfaces.
Upon air evaporation of the solvent system, the resin must form a uniform coherent film without losing its solubility in the solvent.
The processed resin image must be resistant to aqueous solutions.

*Taken from W. S. Deforest, "Photoresist: Materials and Processes," McGraw-Hill Book Co., New York, NY, (1975), p. 21.

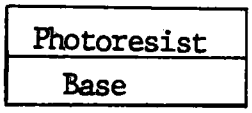
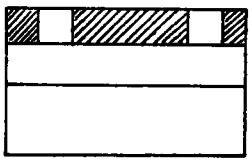
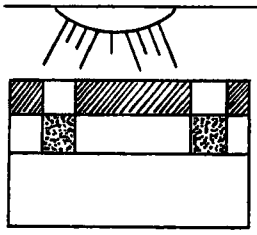
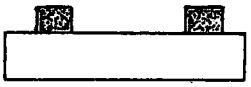
	Negative photoresist is applied uniformly in a thin layer on the circuit board or other base material and dried thoroughly.
Photomask 	A photomask with transparent image areas delineating the desired pattern is brought in close contact with photoresist surface through the use of a vacuum frame or by mechanical means.
	With the photomask in place, the resist is exposed to a light source rich in ultraviolet radiation. The resist film beneath the clear areas of the photomask undergoes a physical and chemical change that renders it insoluble in the developing solution.
	After exposure, the resist-coated base is immersed in the developing solution, which allows the unexposed areas to be removed without excessive effect on the hardened or exposed area. The resulting image can be further hardened by baking or rendered more visible by dyeing or both. The base can be etched.

Fig. 3. Negative photoresist process.*

* W. S. Deforest, "Photoresist: Materials and Processes," McGraw Hill Co., New York, NY, (1975), p. 2.

Positive photoresists, on the other hand, are solubilized by exposure. After development, the exposed material is then removed either by wet chemical or plasma etching.

The final step in using a photoresist film for photoengraving purposes is the removal from the substrate. Successful stripping is a significant contributor to yield and cost of component manufacture, and incomplete removal of photoresist will most assuredly create problems in subsequent operations. This final removal is a tedious task because of the insolubility of these compounds. The degree of difficulty depends on the nautre of the photoresist film, its thickness, and the underlying substrate.[3]

Chemical stripping of photoresists through the use of hot and cold solvents is common in the manufacture of semiconductor devices.[6,7] The cold solvent stripper has, as its primary constituent, methylene chloride fortified with lower alcohols and ketones, an acid and a wetting agent.[7] It may also contain parafin wax to retard evaporation, phenols, cresols, xylene, hydrocarbon solvents, and esters.[7] It strips by swelling and lifting of the photoresist film with some dissolution and, for a complete removal of the residues, some scrubbing action is usually necessary.[7]

The hot solvent stripper removes photoresists primarily by dissolution,[7] and both acid and alkaline solutions are available. Both types of solutions utilize phenols and/or cresols, which are not very desirable constitutents because of accompanying contamination of parts.[7] Chlorinated benzenes, high-boiling aliphatic chlorianted

hydrocarbons, mineral acid, and aromatic aldehydes may also be present in the acid solution.[7] The most widely used wet chemical stripping relies on hot chlorinated hydrocarbons to swell the polymer, in conjunction with acids to reduce the adhesion to the substrate.[9] Hot sulfuric acid, an oxidizing agent, may be used to decompose organic material, but film corrosion often prohibits such drastic action.[9] However effective this process may be, several disadvantages are inherent; for example, due to possible sodium contamination, it is not advisable to use a typical chromicsulfuric acid mixture in the removal of photoresist from Metal Oxide Semiconductor (MOS) devices.[2] Sodium is a common contaminant in these mixtures and its presence is detrimental to the electrical characteristics of bipolar and MOS devices.[11] The mixture can also react with aluminum; therefore, it cannot be used to strip photoresist film from an aluminum metal pattern.[11] One also runs the risk of dissolving the first layer metallization by use of acidic solutions on circuits which have multilayer cross-over metallization patterns.[7] The use of these solvent strippers is limited to metal parts or parts with no exposed plastics on the substrate for fear of the damage that might occur.[7]

Some of the problems associated with wet chemical processing are chemical shortages, cleanliness, maintenance, rising costs, operator safety, and disposal of chemicals. Wet chemical processes also require constant attention to monitor chemical consistency.[3] The slightest trace of photoresist film left on aluminum or other metal surfaces can have a deleterious effect on subsequent wire bonding operations.[12] Complete removal,therefore, is very important. Also of a major concern

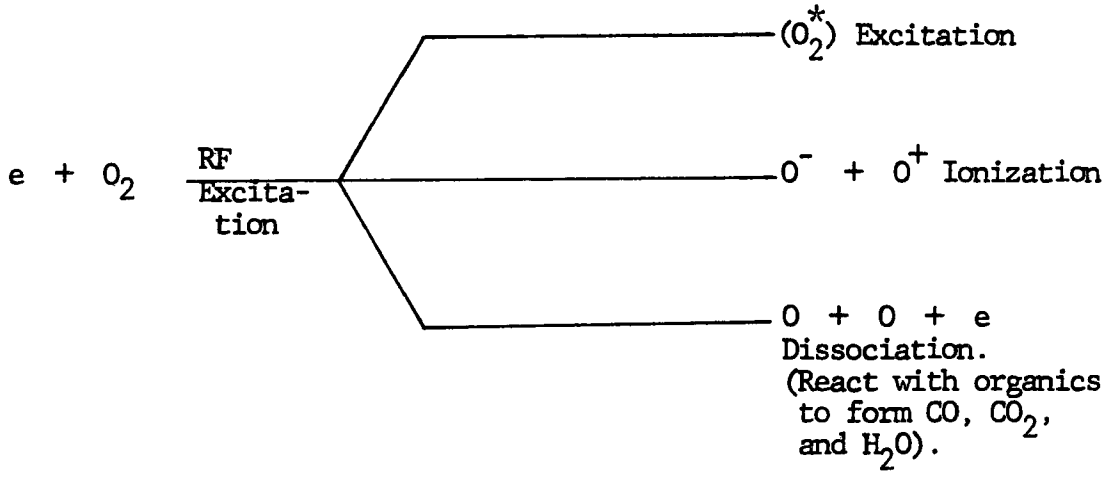


Fig. 4. Molecular oxygen dissociation by excitation reactions.

to semiconductor manufacturing is the possibility of device contamination and if this becomes responsible for device rejection late in the production process, the financial loss may be substantial.

An alternative process for stripping photoresist that is clean, convenient, and subject to less contamination[2] is the Oxygen Plasma. It is based upon the oxidative degradation of polymeric material by reactive species produced in the plasma.[13] The species O^+, O_2^+, O^-, O_2^-, $O(^3P)$, $O_2(^1\Delta)$ and free electrons have been identified in the oxygen plasma and the oxidative reactions have been attributed to atomic oxygen $O(^3P)$. The formation of active oxygen O*, is the result of molecular oxygen dissociation caused by excitation reactions due to electron bombardment[9] (Fig. 4). Its attack on the unsaturation within the photoresist can be attributed to the electrophilic character of atomic oxygen.[9] This highly reactive medium converts the organic photoresist to low molecular weight volatiles such as CO_2, H_2O, and CO, which are then pumped away.[2,7,11] The subsequent attack of oxygen atoms on the free radicals produces CO, CO_2, OH and hydrogen atoms.[9,14] A suggested sequence[9] is:

Photoresist (e.g. CH_2-CH(-C(=CH_2)-CH_3)) + O* ⟶ CH_3, HCO, OH (1)

$$CH_3 + O^* \longrightarrow H_2CO + H \quad (2)$$

$$HCO + O^* \longrightarrow OH + CO \quad (3)$$

$$HCO + O^* \longrightarrow H + CO_2 \quad (4)$$

$$OH + O^* \longrightarrow O_2 + H \quad (5)$$

$$O^* + CO + M \text{ (Chamber Wall)} \longrightarrow CO_2 + M \quad (6)$$

$$OH + H_2CO \longrightarrow H_2O + HCO \quad (7)$$

$$O^* + H_2CO \longrightarrow CO + H_2O \quad (8)$$

Determining the amount of time necessary for complete photoresist removal with plasma is often a problem. Some of the commercially available equipment is built with an endpoint detector. Such detectors monitor the emission of CO which is a by-product of photoresist stripping. This has proven ineffective, however, because there has often been photoresist left on the wafers after the endpoint indication.[15]

Several factors are known to cause plasma stripping to proceed non-uniformly. Any one or a combination of these can result in incomplete removal of the photoresist from at least part of the lot. There may be non-uniformity of stripping rate related to wafer position within the reaction chamber, or wafers with different types or thicknesses of photoresist may be present. Most equipment exhibits loading effects;[6] that is, the time to completion depends on the number and photoresist thickness of the wafers being stripped. Exposure of devices to the plasma for periods longer than necessary may result in undesirable effects such as a build-up of oxide on the metal surface, thereby making subsequent electrical contact to the metal difficult.[6]

The objective of this study is to develop an optimum strip method, determine stripping endpoints, and demonstrate the dry plasma as a reliable, cost-effective, production-compatible process.

EXPERIMENTAL

Equipment

Plasma Stripping Apparatus. An LFE Plasma Etcher/Stripper (Model PFS/PDS-1002) was used; a system diagram is shown in Fig. 5. This is a system in which a gaseous plasma, in this case oxygen, is induced by radio-frequency excitation in a cylindrical chamber. The reaction chamber is 18 inches long by 8 inches in diameter (Fig. 6). Oxygen is fed into the chamber through four perforated tubes, evenly spaced along the axis of the chamber. The applied electromagnetic field causes the gas to become excited (more reactive than the normal state). The excited oxygen reacts with the photoresist on wafers placed in the chamber, and the resultant gaseous products are removed from the camber by an external exhaust.

The chamber is generally evacuated to about 0.1 torr and a regulated flow of gas (oxygen) is introduced, which maintains chamber pressure between 0.5 and 1.5 torr. Radio-frequency energy is then applied to the chamber coils for a predetermined time. At the end of the cycle, the system returns to atmosperic pressure. The Oxygen Plasma is operated at a frequency of 13.56 MHz.

IBM 7840 Film Thickness Analyzer. The Film Thickness Analyzer (FTA) consists of a reflectance spectrometer in which the monochrometer element is a variable wavelength interference filter. This spectrometer functions

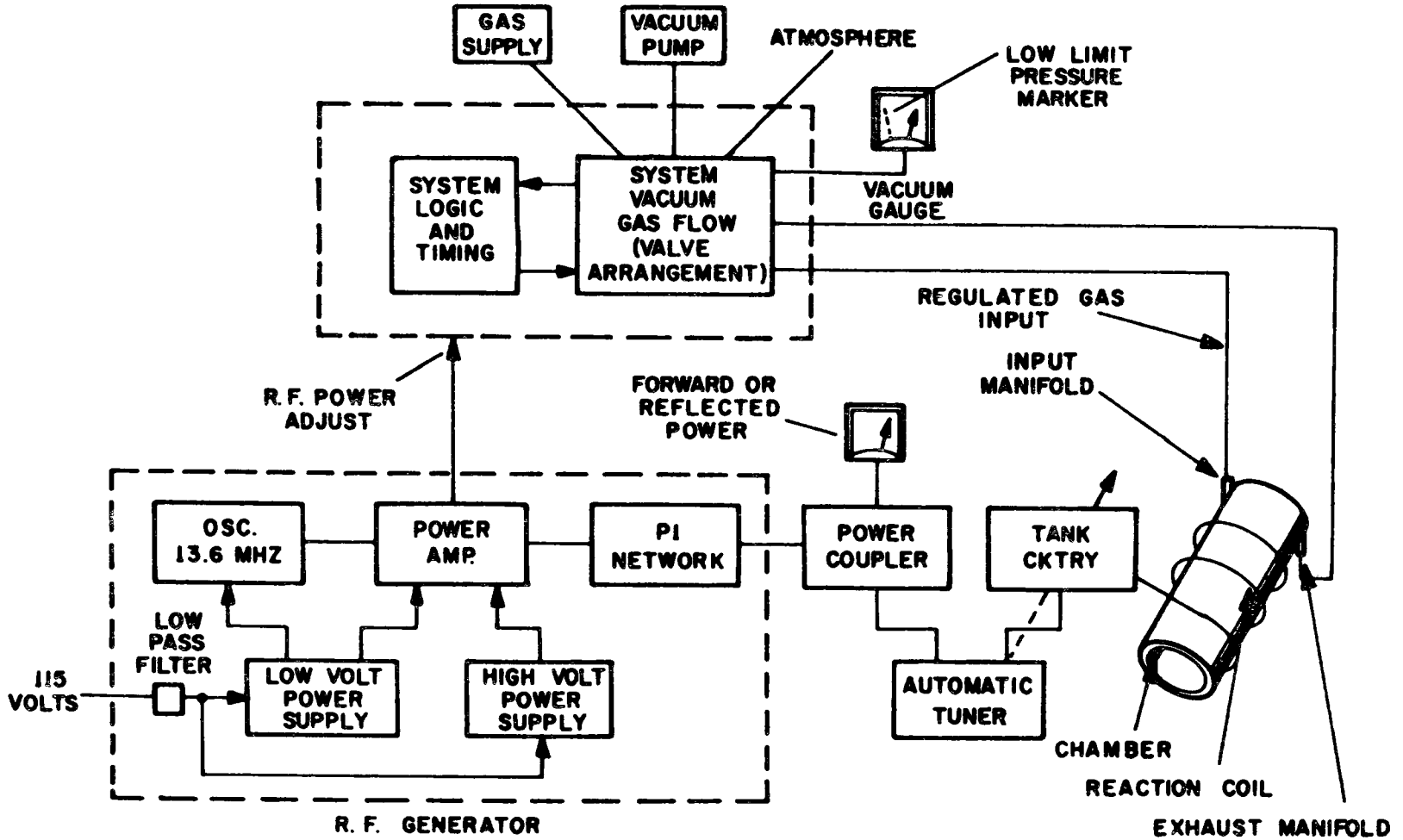


Fig. 5. Plasma system.

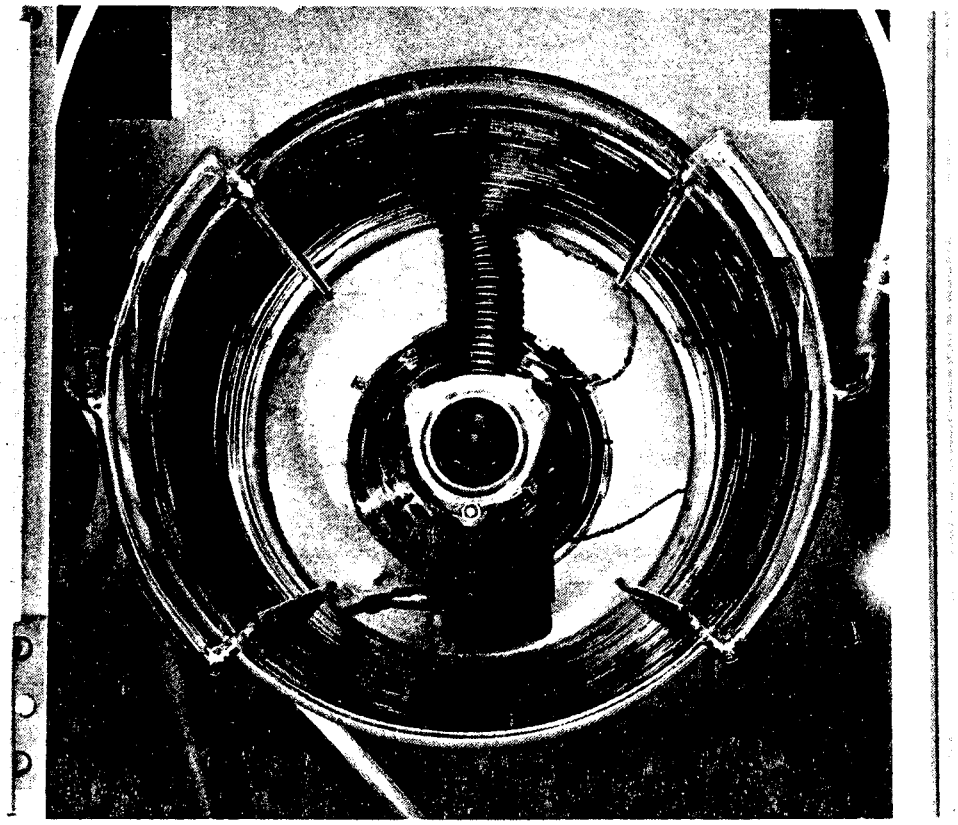
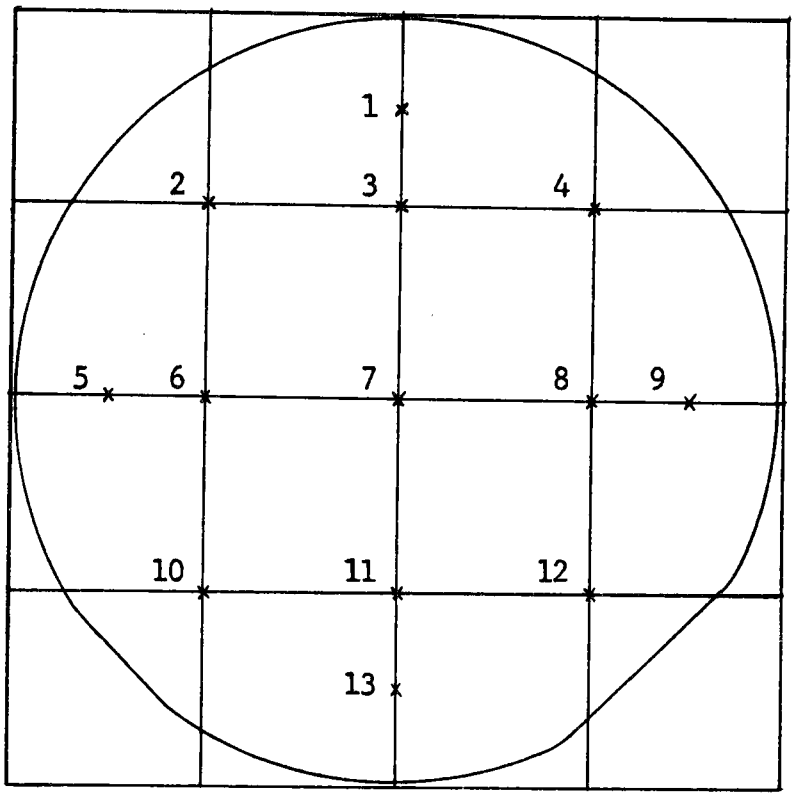


Fig. 6. LFE model - 1002 reaction chamber.



1. 2000, 300
2. 1000, 1000
3. 2000, 1000
4. 3000, 1000
5. 300, 2000
6. 1000, 2000
7. 2000, 2000
8. 3000, 2000
9. 3700, 2000
10. 1000, 3000
11. 2000, 3000
12. 3000, 3000
13. 2000, 3700

Fig. 7. Location of film thickness analysis points on test wafer.

in a two-path mode over the wavelength range of 4000 to 7000Å, and provides data to the computer at 54 sampled wavelengths for each path. One path provides the computer with direct data for use in removing the overall spectral response of the system. The other path includes the reflectance of the film coated wafer which carries with it the information needed for the thickness determination.

Procedure

The silicon wafers (4 in in diameter, 21.0 mils thick) used in all experiments were obtained as bare, oxidized material. They were cleaned and coated with a typical production photoresist, Hunt Resist 43, Type 3IC. The photoresist coating was applied as a liquid, which was spun on the wafer at 6000 rpm for 15 sec, prebaked at 90 C for 7 min, and exposed and developed. The photoresist was then postbaked at 140 C for 7 min, using a Model AF-100 Cobilt Coater/Developer. Additional baking was done in an oven at 150 C for 15 min to remove any remaining solvent and increase photoresist adhesion to the substrate.

Film (photoresist) thickness was measured at thirteen points on each of six wafers (out of a lot of twenty-five) using the Film Thickness Analyzer (Fig. 7). Photoresist thickness varied from about 0.7 micron to 1.2 microns on different lots. The wafers were then placed in a quartz asher boat with the coated surface facing the rear of the chamber and the major flat edge on top. The boat has a capacity for twenty-five wafers in a vertical position at a spacing of 0.1875 in (Fig. 8). Two of the test wafers were located in the front, two in the middle, and two at the rear of the boat. The loaded boat was then placed in the quartz

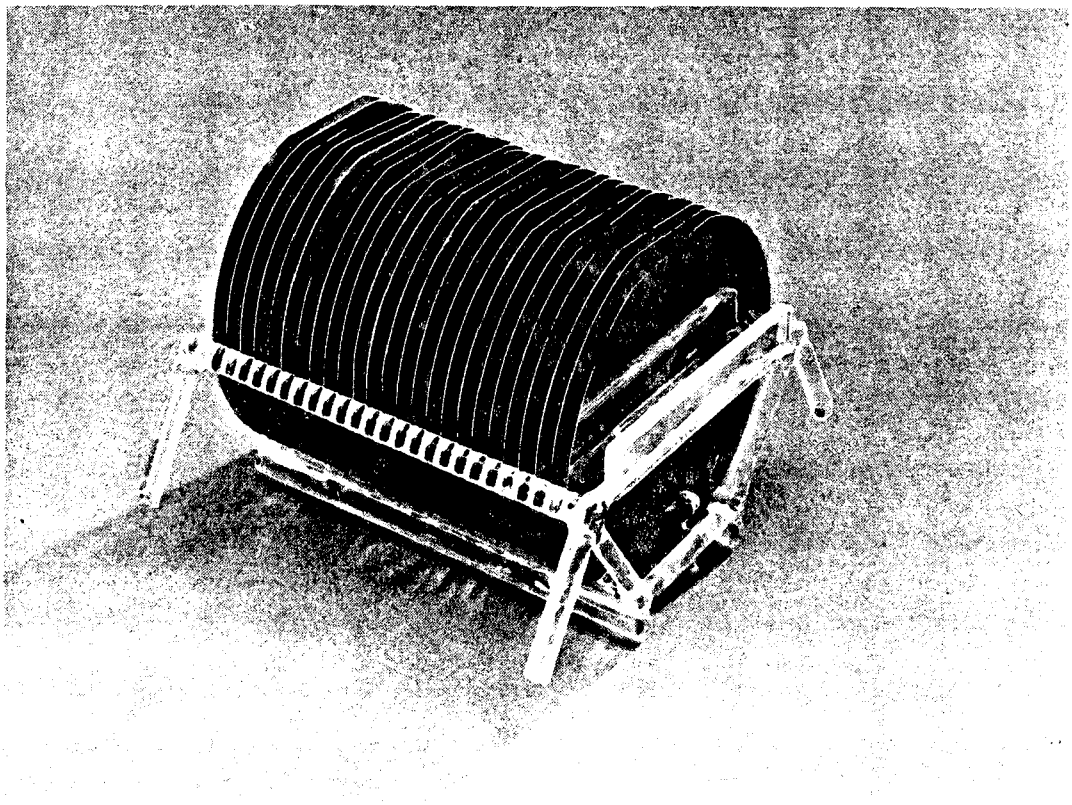


Fig. 8. Quartz asher boat with wafers.

reaction chamber and the stripping process applied. After stripping for a specified time interval, the thickness of the remaining photoresist was again measured at thirteen points on the IBM analyzer. This process was repeated for the various parameter [Power (RF) and Flow Rate] combinations under study. The range of power and gas flow rate chosen for study was determined from the recommendation given in the operator's manual for efficient operation of the plasma equipment. An experimental matrix was designed to encompass a relatively broad range of parametric variation (Fig. 9). The marked columns were initially investigated and, as suggested by the results obtained, more columns were investigated.

After the optimization of process parameters, full lots of twenty-five wafers were stripped at four-minute intervals with the coated surface facing the rear of the chamber. Twelve representative wafers out of the lot were then weighed to a constant weight, using an analytical balance readible to 0.1 mg. The process was repeated with the coated surface facing the front end of the chamber. These results were used to determine the time for complete removal of photoresist and possible effect of photoresist orientation. At the end of this determination, four split lots of AM Receiver with Noise Suppression (DM-42), Tone and Volume Control (DM-116), Audio Processor and Noise Suppressor (DM-105) and Phase-Locked FM Tuning (DM-113), three of Power Control Unit (PCU), and Idle Speed Control (ISC), two of Low Drop Out (LDO), and Electronic Ignition (EI-10), and one of Electronic Module Retard (EMR) wafers were stripped after the metal mask application. (Some of the device functions are shown in the Appendix.) One half of each was stripped with the plasma, the other half with the

Gas Flow Rate (cc/min)

RF Power (watts)

	500	550	600	650	700
500	***		***		***
475		***		***	
450	***		***		***
425		***		***	
400	***		***		***

Fig. 9. Matrix of parametric variation.

standard production wet process using the proprietary "J-100" mixture. The half processed through "J-100" was marked. The stripped lots were reunited, and progressed through standard processing steps as follows:

a. Microalloy; formation of Si-Al alloy on the wafer at 510 C for 15 min (in Diffusion Room).
b. Aging Bake; heating at 400 C for 4 hr, minimizes the amount of photoresist between the silicon and aluminum.
c. Glassivation; application of a layer of pyrolytic glass for protection against surface contamination (in Evaporation Room).
d. Photoresist Spin and Bake; application of SC-180 photoresist by spinning on at 3000 rpm for 15 sec, followed by 7-min prebake at 90 C, exposure and development, and 7-min postbake at 140 C.

The lots were then returned to the chemical processing area and etched. After etching, the lots were again split, with half of each being plasma stripped and the other (marked) half stripped in "J-100." These stripped, split lots (Plasma and "J-100) were then sent to the Failure Analysis Engineers to be evaluated for equivalency in test yield. Wafer yield, wire bonding and electrical tests were performed. One wafer from each of the two processes was also sent for Auger Electron Spectroscopy (AES) and Scanning Electron Microscope (SEM) analysis of the stripped surface.

RESULTS AND DISCUSSIONS

Optimum results were obtained from the oxygen plasma stripping processing with the RF power set at 450 watts and oxygen flow adjusted to 600 cc/min. This combination was chosen because it produced a fairly high strip rate and, at the same time, exhibited the least variation in the amount of stripped photoresist in a given load of wafers (Tables 3a and b). Graphical representation of strip rate uniformity is shown in Fig. 10a, where the amount of material stripped from the front, middle, and rear wafers is plotted against time; this is compared to a previous production setting in Fig. 10b. Absolute uniformity could not be obtained at any combination of settings.

Plasma stripping is a chemical process, so strip rates depend on local temperatures at the surface of the wafer. This temperature dependence imposes limitations on the uniformity of stripping processes. Stripped wafers generally show two kinds of variation, across-wafer and wafer-to-wafer variation. Across-wafer variation accounts for differences in the nature and extent of stripping between two points on the same wafer. Wafer-to-wafer variation is responsible for the differences between two wafers stripped during the same run. Temperature effects contribute greatly to the two types of variation. Across-wafer variation is caused chiefly by local temperature differences on the surface of the wafer during stripping. This is attributed to the overheating of the wafer's periphery due to the action of ions, U.V. radiation, and electric fields. When this

Table 3. Combinations of Power and Gas Flow Rate for Optimum Process Condition.[1]

a.

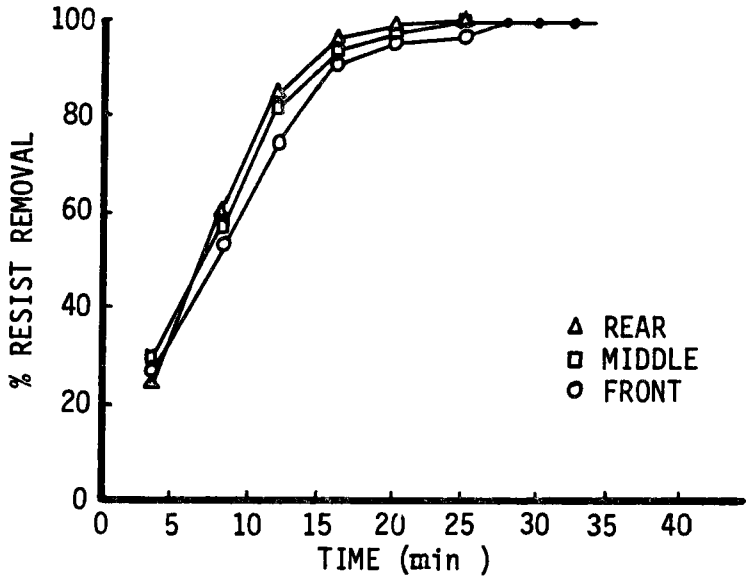
	Gas Flow Rate (cc/min)				
	500	550	600	650	700
500	490.00		596.00		623.00
	178.00		213.50		208.25
475		582.00		584.00	
		189.50		188.75	
450	526.00		571.00		611.00
	135.00		136.25		208.00
425		557.00		580.00	
		149.75		179.50	
400	493.00			179.50	537.00
	106.75		128.50		153.75

b.

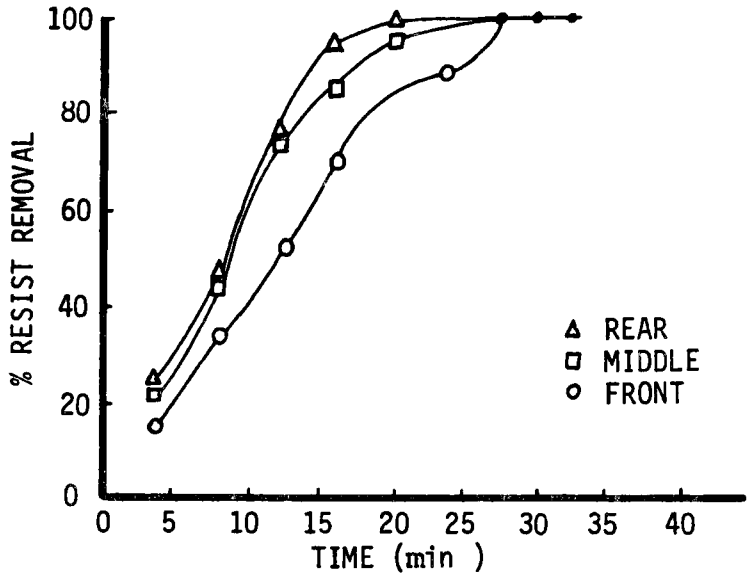
	600	650	700
500		620.00	
		204.25	
475	585.00		612.00
	178.00		211.75
450		584.00	
		188.75	

Strip Rate Å/Minute
Variation[2] Å

[1] Where a is the initial investigation, and b is the final investigation.
[2] This is the difference in amount of photoresist stripped from wafer to wafer in a given load of wafers.



ⓐ. Settings at 450 watts, 600 cc/min.



ⓑ. Settings at 400 watts, 550 cc/min.

Fig. 10. The variation of photoresist removal with wafer position.

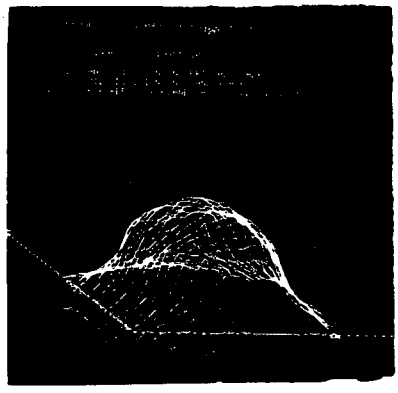
occurs, stripping proceeds very rapidly on the periphery. Variation in wafer-to-wafer uniformity is a result of wafers placed at different points within a reactor being heated to different temperatures. Overheating may occur at some points if heat flow and gas flow within the reactor are not uniform.

From Fig. 10, it is noted that the wafers near the rear of the chamber are stripped more quickly then those positioned near the front. It seems evident from these results that there may exist an apparatus design problem. Another factor that needs to be considered in terms of nonuniformity of stripping is the variable thickness of photoresist (see Fig. 11). Examples of photoresist application topography shown in Figs. 11a through 11c illustrate the wide variation which can occur. Nonuniformity of photoresist removal is bound to result from such extreme thickness variability, unless sufficient stripping time is allowed.

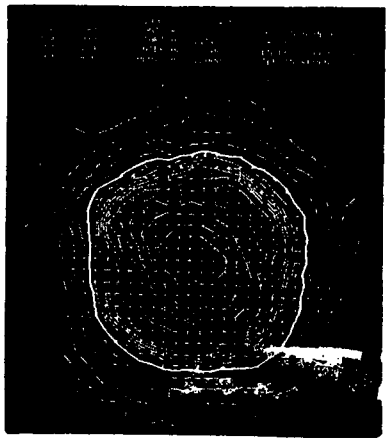
Generally, there is an increase in strip rate, up to a certain point, as the power, oxygen flow rate, and chamber pressure increase, (but with further increase of these variables the rate starts to decrease). At higher pressures, atomic oxygen recombines to a great extent,[16] reducing the effective concentration for reaction. The decrease in rate at higher pressure can also be attributed to a decrease in the mean free path of the active atomic species between wafers.[8] The same reasoning applies to the gas flow rate since an increase in flow rate leads to an increase in pressure. Also, there may be more oxygen present than the energy density (power) requires to cause excitation; at this point, an increase in flow rate does not promote the strip rate. As the power is increase beyond an

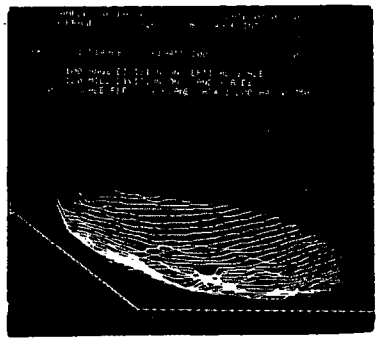
3 Dimensional View

Top View

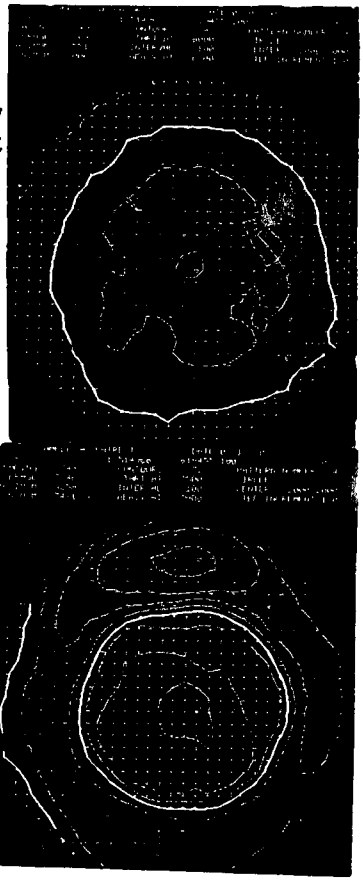


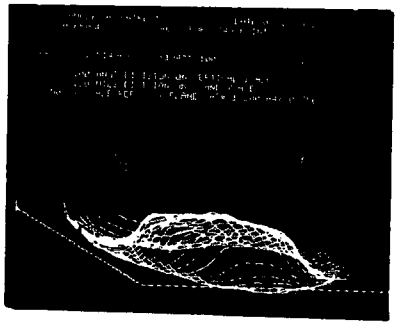
a. Center of Wafer is Heavily Coated with Photoresist





b. Center is Thin; Outer Edges are Heavily Coated with Photoresist





c. Center is Proportionally Thicker than the Outer Edges of Wafer [normal application]

Fig. 11. Varying application of photoresist (wafer contour mappings).

optimum value, the chamber walls become heated, and strip rate decreases (increase in the wall temperature decreases strip rate). According to J. R. Hollahan, R. F. power should be at a level just above that necessary to sustain the plasma.[16]

The endpoint for photoresist removal was determined, by weight loss, to be 35 (±1) min (Fig. 12). Weighing to constant weight on the analytical balance gave an indication of complete removal at a slightly lesser time (about 32 min). However, this was not quite adequate because there were minute traces of photoresist on the surface of the wafers, weighing less than 10 mg (below the sensitivity of the balance). Therefore, the stripping was continued and the surface visually inspected (with use of microscope) until all traces of the photoresist were gone. The total time was 35 (±1) min. There was no significant difference in the endpoint of photoresist removal between wafers facing the rear or front end of the chamber. Figure 13 is a representation of the strip rate during the endpoint determination. It shows an initial rapid increase, followed by a decrease as the amount of photoresist left on the wafer surface is decreased, then by a levelling off as the last stubborn traces are removed. There is no absolute predictable rate of photoresist removal from silicon wafers. The removal rate of photoresist depends on the following factors:[17]

a) The concentration of active oxygen species that react with the photoresist. This to a large extent, is a function of reaction pressure, oxygen flow rate, and the amount and type of impurities in the oxygen.

b) The location, spacing, and number of wafers in the chamber.

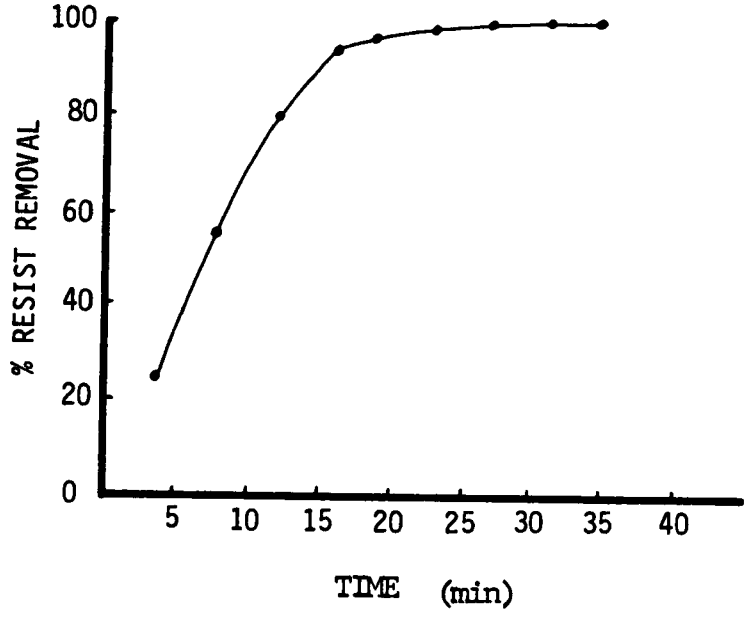


Fig. 12. Percent resist removal vs. time

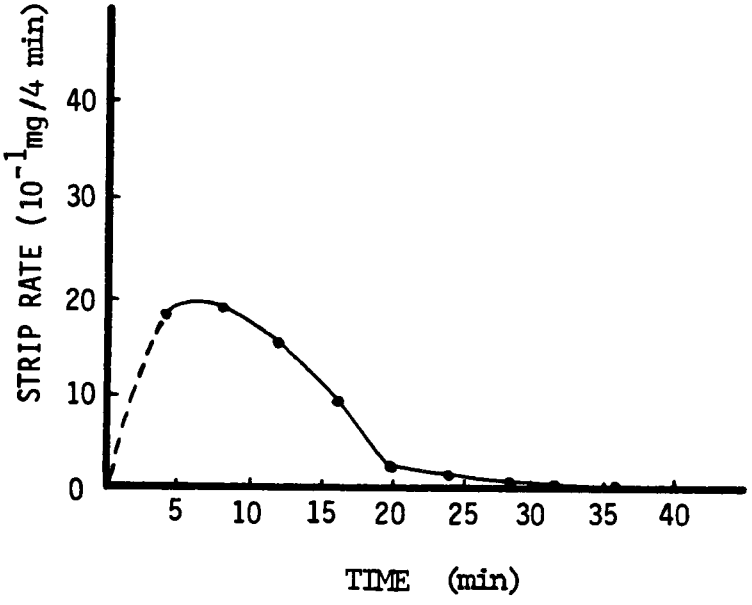


Fig. 13. Photoresist strip rate.

c) The plasma flow characteristics, which are a function of the method of dispersion of the oxygen in the chamber, the location and method of coupling RFpower into the gas, and the method of concentrating plasma in the area of the wafers.

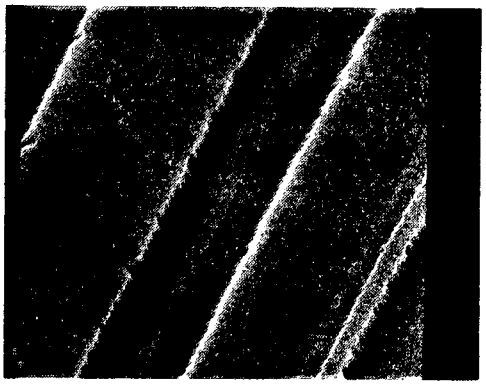
d) The applied RF power level, the efficiency of RF power coupling, and the limit of operating temperature.

e) The type and thickness of photoresist used and the bake time-temperature relationship.

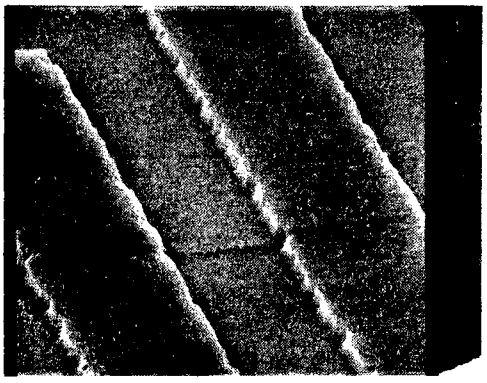
f) The geometry of the quartz boats that hold the wafers in the chamber.

The Scanning Electron Microscope (SEM) analysis showed that there were no photoresist residues or other surface distinction between the wafers that were stripped in J-100 mixture and the Oxygen Plasma (Fig. 14). In other words, the plasma stripping process removed photoresist just as well as the J-100 mixture. Although the wafer surfaces from both processes seem to be equally clean, the plasma process should ultimately prove to be the better cleaning method. This is true because it eliminates the inherent contamination in the J-100 method. The plasma process is dry, uses non-corrosive gas, and the resultant byproducts are volatiles that are evacuated from the chamber during stripping. It eliminates wash and rinse cycles and excessive handling by operators, which are sources of contamination.

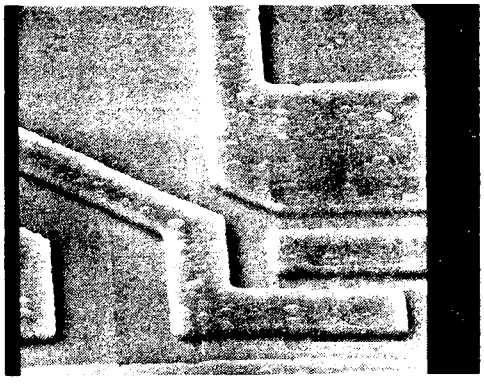
To verify oxygen plasma methods of stripping photoresist; it was necessary to demonstrate that the wafer surface after stripping did not have any significant organic residue left and that the surface was clean.



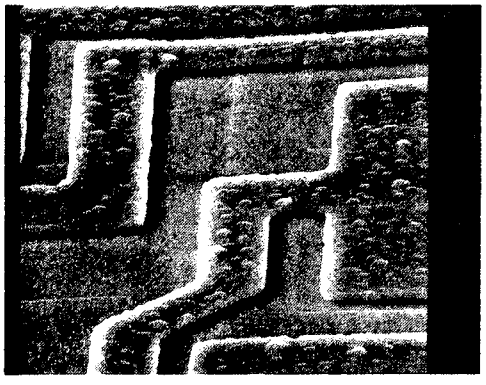
ⓐ. Wafer Surface After Metal Mask Strip [J-100]



ⓑ. Wafer Surface After Metal Mask Strip [Oxygen Plasma]



ⓒ. Wafer Surface After Glass Mask Strip [J-100]



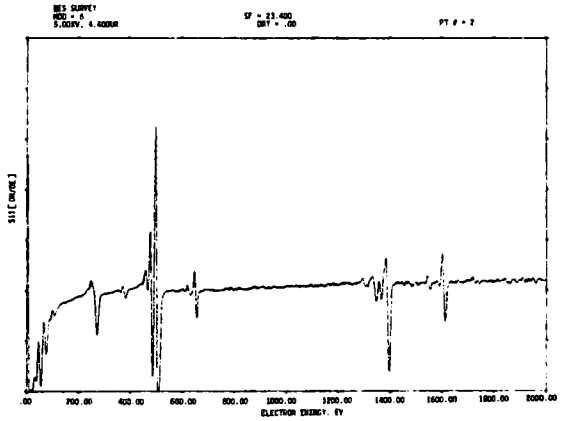
ⓓ. Wafer Surface After Glass Mask Strip [Oxygen Plasma]

Fig. 14. SEM analysis of wafer surfaces after J-100 and oxygen plasma stripping.

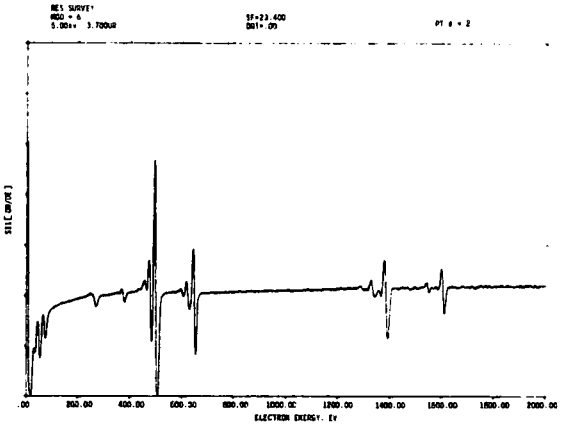
Figure 15a shows an AES surface survey spectrum of a non-plasma (J-100) treated metallization sample. The surface was acceptably clean (atomic percent carbon, 7.6). Figure 15b shows corresponding AES data for the same device after oxygen plasma stripping. The surface was seen to be cleaner, with respect to carbon residue, than the surface examined on Fig. 15a (atomic percent carbon, 2.6). In a similar application, analyses like those of Fig. 15 were performed on glass passivation materials. The results from the J-100 and plasma treated samples can be seen in Fig. 16. Again, the surface of the sample through the J-100 wet process was acceptably clean (atomic percent carbon, 6.0) and that of the plasma process (atomic percent carbon, 2.4) proved to be cleaner.

The spectra discussed above suggest that there was some trace of carbon left on the surfaces of the wafers, with those processed through the J-100 mixture having more. However, this amount of carbon did not prove to be significantly deleterious in subsequent operations. The presence of fluorine in the Auger spectra may have resulted from the decomposition of CF_4O_2 which is used for etching in the plasma system and probably adsorbed on the system walls. The presence of nitrogen has yet to be explained.

Electrical testing to distinquish good integrated circuits from defective ones was done by the Failure Analysis engineers using a probe card carrying an array of extremely fine needlelike probes, which establish contact with the circuit pads. The result showed no significant difference in yield between the two processes. After yield test, each wafer was sectioned to separate individual chips, by simply

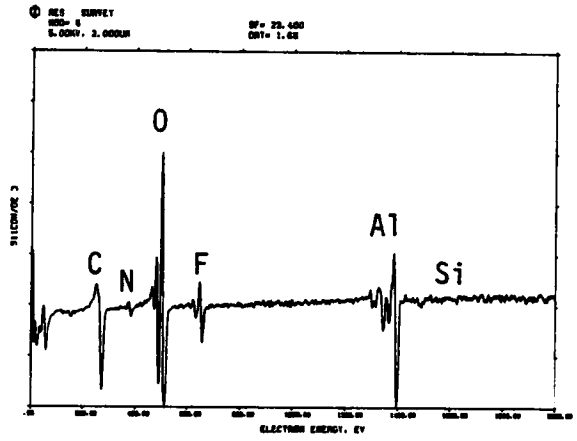


ⓐ. Surface Spectrum of "J-100" Stripped Wafer After Metal Mask

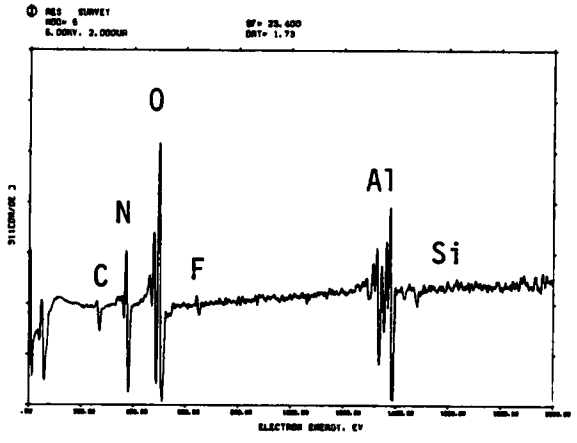


ⓑ. Surface Spectrum of Oxygen Plasma Stripped Wafer After Metal Mask

Fig. 15. AES surface analysis of J-100 and oxygen plasma treated wafers after metal mask.



ⓐ. Surface Spectrum of "J-100" Stripped Wafer After Glass Mask



ⓑ. Surface Spectrum of Oxygen Plasma Stripped Wafer After Glass Mask.

Fig. 16. AES surface analysis of J-100 and oxygen plasma treated wafers after glass mask.

scribing between the chips and breaking the wafer along the scribe line. The good circuits were wire bonded into integrated circuit packages. The fine gold wire leads (1 mil in diameter) were connected from the bonding pads of the dice to the paddles of the lead frame. The packaged circuit was then sealed and the device sent for final testing. Again, no differences were noted during the wire bonding operation. (It is known, however, that the J-100 process in many instances poses wire bonding problems due to residue contamination of bonding pads. The plasma process is expected to circumvent this problem.)

The final test, also known as functional testing, was done to verify the effect of normal operating conditions on the plasma processed products. No degradation of parts was detected.

These results showed that the plasma process is production compatible.

CONCLUSION

The complete removal of photoresist was accomplished in 35 min with the use of LFE Model PFS/PDE/PDS-1002 plasma stripper at an RF power level of 450 watts and oxygen flow rate of 600 cc/min. Microscopic examination of stripped wafers failed to reveal any significant residual photoresist on the surfaces, although traces of nitrogen and fluorine were found through Auger analysis.

Plasma stripping has been found to be fully compatible with all stages of integrated circuit fabrication. It offers several advantages over the wet process, including:

1. Reduced manufacturing cost through reduced stripping material and handling costs;
2. Improved device yields (because the processing is clean and simple);
3. Production line simplification;
4. By-products of plasma reactions are environmentally compatible;
5. Eliminates monitoring of chemical consistency;
6. Elimination of chemical hazards to workers;
7. Elimination of acid storage and disposal;
8. Meets EPA and OSHA requirements; and,
9. Reduced manufacturing area (acid baths and hoods are eliminated).

Despite several technological advances in plasma stripping, the full exploitation of plasma stripping in integrated circuit manufacturing

remains limited by difficulties in endpoint determination, and the problem of non-uniform stripping. To obtain reproducible strip times, load geometries including layer thicknesses must be accurately reproduced from run to run. Much work remains to be done in understanding the mechanism of the reactions in the plasma chamber.

The plasma method constitutes the most encouraging technique both in terms of surface cleanliness and practicability. The estimated annual savings resulting from this process change is $163,000.

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APPENDIX

Delco Electronics Bipolar Devices

DM-113 Phase-locked FM tuning. This bipolar circuit is 101 mils square and includes in its circuitry an I^2L low-current divider section, a T^2L high-speed logic divider, a down-conversion mixer, and a digital phase detector.

The FM oscillator is tuned by mixing it with 76 and 72.1 MHz, dividing it down, and comparing it to a divided-AM oscillator frequency in the phase detector, which generates a feedback to the FM oscillator to correct phase errors.

DM-105 Audio processor/noise suppressor. This bipolar IC is 64 by 75 mils in size and contains 80 transistors and diodes and 63 resistors. This unit combines the functions of the DM-45 and DM-46.

It compensates for increased noise under low-signal conditions by summing the right and left channels, thus reducing noise content. High frequency response is also automatically reduced under low-signal conditions, thus cutting down on "hiss" in the audio signal. This circuit also senses extraneous noise impulses in the signal and removes them by blanking the audio signal for an appropriate time.

PCU Power control unit. This IC, which is 131 by 146 mils, is produced using a mixed bipolar and I^2L process. It incorporates many functions including voltage regulation, clock signal generation, spark signal transfer and control in limp-home mode, along with a number of

system functions in the C4 and TBI Computer systems.

EIC (EI-10 and EMR) Electronic ignition. The EIC integrated circuit is a bipolar flip chip which is 64 x 74 mils in size. It contains 12 transistors, 9 diodes and 24 resistors.

This chip and its associated circuitry process the input from a magnetic distributor pickup and convert it to a high energy ignition pulse. The entire assembly replaces the conventional mechanical breaker point ignition system on all GM cars.

LDO (Low Drop-Out) Regulator. This bipolar IC, 80 x 64 mils, is the 8V regulator in the computer command control unit. The main feature of this regulator is that the input can be as low as 9V and the output will be regulating at 8V over a range of temperatures from -40 C to +124 C.

DM-116. This bipolar IC, 96 mils square, provides for electronically controlling the tone response and volume level for the two audio channels in the radio and also provides for the balance function between the two channels. The three parameters are varied by means of DC control voltage inputs.

ISC (Idle Speed Control). This bipolar IC, 100 mils square, receives a digital input from the engine control unit which is converted to a 2 amp output current which turns a motor that controls the idle speed adjustment on the carburetor. This IC as with all engine control IC's must operate over a temperature range of -40 C to +125 C.

DM-42 AM receiver and noise suppression. This bipolar IC, is 80 x 85 mils. It contains 128 transistors, 85 resistors, and 3 capacitors.

The IC contains 11 individual stages such as double balanced mixer, oscillator, wide band AGC detector, narrow band AGC detector, audio detector, noise blanker, 3 I.F. amplifier stages, stop/start comparator and audio attenuator.